Fabrication of optical planar waveguides in $KY(WO_4)_2$ by He-ion implantation

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$KY(WO_4)_2$ represents an outstanding host material for fabricating both bulk and waveguide lasers, when doped with different rare-earth elements. Ion implantation can be regarded as a universal tool for fabricating low-loss waveguide structures in optically active oxide materials [1]. In this contribution we report, for the first time to our knowledge, results obtained when implanting light ions, such as H^+ or He^+, into undoped and Yb-doped $KY(WO_4)_2$ crystals.

Optically polished crystals, which were kept at a controlled temperature of 30°C and oriented along the (010) axis, were irradiated by use of a Van de Graaf accelerator operating at beam currents in the range of 0.6-0.8 mA/cm^2. The accumulated damage profiles created by the implanted ions were calculated by the SRIM simulation code. The effective refractive indices of guided modes in surface planar waveguides were measured by dark m-line spectroscopy and the refractive index profiles were reconstructed by calculations based on the inverse WKB method. The end-faces of implanted crystals were polished and the waveguiding properties of the obtained planar structures were investigated using a laser diode at 980 nm and a CCD camera.

He^+ ions at 1.5 MeV with doses ranging from 1 to 3x10^{16} ions/cm^2 were implanted into $KY(WO_4)_2$ crystals. An optical barrier with a decreased effective refractive index has been created at the end of the ions' tracks, situated approximately 3.5 µm below the surface (Fig. 1a). Fig. 1b shows the refractive index as a function of depth for the sample implanted with a dose of 3x10^{16} ions/cm^2. The measurement by m-line spectroscopy revealed that six modes at 633 nm were confined in the region between the optical barrier and the crystal's surface. The change in refractive index along the n_m axis is of the order of –10% with respect to the bulk value. Annealing at 250°C for 2 hrs resulted in better confinement of the modes in the waveguiding region. Near-field images of light guided through the multimode He-implanted waveguide were recorded after coupling 980-nm light from a single-mode laser diode into the 3.5-µm layer with ×40 microscope objectives. Fig. 1c shows the profile of a near-field image obtained on an undoped crystal, after thermal treatment at 250°C for 2 hrs. All results obtained on undoped samples have been confirmed on 2% Yb-doped $KY(WO_4)_2$ crystals.

H^+ ions were also implanted at energies around 1 MeV and doses from 1 to 6x10^{16} ions/cm^2 into $KY(WO_4)_2$ crystals. For this energy, SRIM simulations predict a proton damage distribution peaked around 10 µm below the surface. The m-line measurements confirmed the presence of an optical barrier at this depth, but the modes were poorly confined compared with the He-implanted waveguiding modes. The change in effective refractive index was also negative, on the order of –2.6% for the highest dose. End-coupling of laser light into the 10-µm layer using different microscope objectives was unsuccessful, even after successive thermal treatments up to 300°C. For proton implantation, the dominant effect causing the negative index modification might stem from an electronic excitation mechanism, which would be highest close to the surface and abruptly decrease at the end of the ions' tracks. Therefore, the 10-µm layer created by proton implantation might be modified entirely by interaction with the protons' charges and present high losses but no waveguiding properties.

In conclusion, planar waveguides produced by He-ion implantation have been demonstrated in undoped and Yb-doped $KY(WO_4)_2$ crystals for the first time. The fabrication of channel waveguides by He-ion implantation through masks is in progress.

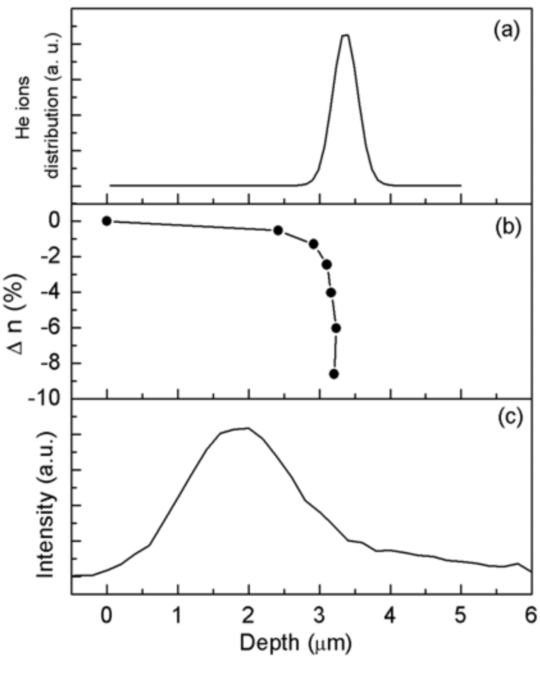

Fig.1 Surface planar waveguide in $KY(WO_4)_2$ formed by He-ion implantation. (a) Accumulated damage profile calculated by SRIM simulations for He ions at 1.5 MeV; (b) change in effective refractive index measured by dark m-line spectroscopy and reconstructed by the inverse WKB method; (c) near-field intensity profile along the n_m axis experimentally recorded at 980 nm.

[1] L. Laversenne, P. Hoffmann, M. Pollnau,, P. Moretti, J. Mugnier, Appl. Phys. Lett. **85**, 5167 (2004).